1.1 Ontstaan oceanen en leven

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The Milky Way shines over the ocean horizon. Stars and sea share a common origin.

ORIGINS

Stars and Seas

To understand the ocean, we need to understand how it formed and evolved through time. Since the world ocean is the largest feature of Earth's surface, it should not be surprising that we believe the origin of the ocean is linked to the origin of Earth. The origin of Earth is linked to that of the solar system and the galaxies.

The origin of Earth and the ocean is a long and wonderful story—one we've only recently come to know. As you read this chapter, you may be startled to discover that most of the atoms that make up Earth, its ocean, and its inhabitants were formed within stars billions of years ago. Stars spend their lives changing hydrogen and helium into heavier elements. As they die, some stars eject these elements into space during cataclysmic explosions. The sun and the planets, including Earth, condensed from a cloud of dust and gas enriched by the recycled remnants of exploded stars.

Our ocean is not a direct remnant of that cloud, however. Most of the ocean formed later, as water vapor trapped in Earth's outer layers escaped to the surface through volcanic activity during the planet's youth. The vapor cooled and condensed to form an ocean. Comets may have delivered additional water to the new planet's surface. Life originated in the ocean soon after, developing and flourishing in the ocean for more than 3 billion years before venturing onto the unwelcoming continents. Life and Earth have grown old together. 2.1

The Origin of Earth

2.2

We have always wondered about our origins—how Earth was formed, how the ocean arose, and how life came to be. In the last 50 years researchers using the scientific method have determined a tentative age for the ocean, Earth, and the universe. They have developed hypotheses about how matter is assembled, how stars and planets are formed, and even how life may have arisen. Many of the details are still sketchy, of course, but these hypotheses have predicted some important recent discoveries in subatomic physics and molecular biology. Perhaps the most dramatic twentieth-century discoveries in natural science have been those dealing with the origin and history of the universe.

The universe apparently had a beginning. The **big bang**, as that event is modestly named, occurred about 14 billion years ago. All of the mass and energy of the universe are thought to have been concentrated at a geometric point at the beginning of space and time, the moment when the expansion of the universe began. We don't know what initiated the expansion, but it continues today and will probably continue for billions of years, perhaps forever.

The very early universe was unimaginably hot, but as it expanded it cooled. About a million years after the big bang, temperatures fell enough to permit the formation of atoms from the energy and particles that had predominated up to that time. Most of these atoms were hydrogen, then as now the most abundant form of matter in the universe. About a billion years after the big bang, this matter began to congeal into the first galaxies and stars.

Hubble Space Telescope, STScI

FIGURE 2.1 This spiral galaxy in the constellation Coma Berenices is very similar in size and structure to our own Milky Way galaxy. The galaxy, photographed in 1999 by the Hubble Space Telescope, is 62 million light-years away and about 56,000 light-years in diameter. The stars in the foreground are in our galaxy. Note the clouds of dust and gas that obscure our view of some parts of the spiral arms. Planets and oceans are made of such material.

Galaxies and Stars

2.3

A **galaxy** is a huge rotating aggregation of stars, dust, gas, and other debris held together by gravity. Our galaxy is named the **Milky Way galaxy** (from Greek *galaktos* = milk).[1] A galaxy very similar to our own is shown in **Figure 2.1**.

The **stars** that make up a galaxy are massive spheres of incandescent gases. They are usually intermingled with diffuse clouds of gas and debris. In spiral galaxies like the Milky Way, the stars are arrayed in curved arms radiating from the galactic center. Other galaxies are elliptical or irregular in shape. Our part of the Milky Way is populated with many stars, but distances within a galaxy are so huge that the star nearest the sun is about 42 trillion kilometers (26 trillion miles) away. Astronomers tell us there are perhaps 100 billion galaxies in the universe and 100 billion stars in each galaxy. Imagine more stars in the Milky Way than grains of sand on a beach![2]

Our sun is a typical star (**Figure 2.2**). The sun and its family of planets, called the **solar system**, is located about three-fourths of the way out from the galaxy's center, in a spiral arm. We orbit the galaxy's brilliant core, taking about 230 million years to make one orbit—even though we are moving at about 280 kilometers per second (half a million miles an hour). Earth has made about 20 circuits of the galaxy since the ocean formed.

[1] Because they can be useful as well as interesting, the derivations of words are sometimes included.

[2] In July 2003 astronomers announced that their survey of the total number of stars in the known universe had reached 70 sextillion—about ten times more stars than grains of sand on all the world's beaches and deserts!

FIGURE 2.2 A filament of hot gas erupts from the face of our sun. Like all normal stars, our sun is powered by nuclear fusion—the welding together of small atoms to make larger ones. These violent reactions generate the heat, light, matter, and radiation that pour from stars into space. The entire Earth could easily fit into this filament's outstretched arms.

The Lives of Stars

2.4

As we will see, most of the substance of Earth and its ocean was formed by stars. Stars form in **nebulae**, large, diffuse clouds of dust and gas within galaxies. With the aid of telescopes and infrared sensing satellites, astronomers have observed such clouds in our own and other galaxies. They have seen stars in different stages of development and have inferred a sequence in which these stages occur. The **condensation theory**, a theory based on this inference, explains how stars and planets are believed to form.

The life of a star begins when a diffuse area of a spinning nebula starts to shrink and heat up under the influence of its own weak gravity. Gradually the cloudlike sphere flattens and condenses at the center into a knot of gases called a **protostar** (*protos* = first). The original diameter of the protostar may be many times the diameter of our solar system, but gravitational energy causes it to contract, and the compression raises its internal temperature. When the protostar reaches a temperature of about 10 million degrees Celsius (18 million degrees Fahrenheit), nuclear fusion begins; that is, hydrogen atoms begin to fuse together to form helium, a process that liberates even more energy. This rapid release of energy, which marks the transition from *protostar* to *star*, stops the young star's shrinkage. (The process is shown in the top half of **Figure 2.3**.)

After fusion reactions begin, the star becomes stable—neither shrinking nor expanding, and burning its hydrogen fuel at a steady rate. Over a long and productive life, the star converts a large percentage of its hydrogen to atoms as heavy as carbon or oxygen. This stable phase does not last forever, though. The life history and death of a star depend on its initial mass. When a medium-mass star (like our sun) begins to consume carbon and oxygen atoms, its energy output slowly rises and its body swells to a stage aptly named *red giant* by astronomers. The dying giant slowly pulsates, incinerating its planets and throwing off concentric shells of light gas enriched with these heavy elements. But most of the harvest of carbon and oxygen is forever trapped in the cooling ember at the star's heart.

Stars much more massive than the sun have shorter but more interesting lives. They too fuse hydrogen to form atoms as heavy as carbon and oxygen; but because they are larger and hotter, their internal nuclear reactions consume hydrogen at a much faster rate. In addition, higher core temperatures permit the formation of atoms up to the mass of iron.

The dying phase of a massive star's life begins when its core—depleted of hydrogen—collapses in on itself. This rapid compression causes the star's internal temperature to soar. When the infalling material can no longer be compressed, the energy of the inward fall is converted to a cataclysmic expansion called a **supernova**. The explosive release of energy in a supernova is so sudden that the star is blown to bits and its shattered mass is accelerated outward at nearly the speed of light. The explosion lasts only about 30 seconds, but in that short time the nuclear forces holding apart individual atomic nuclei are overcome—and atoms heavier than iron are formed. The gold of your rings, the mercury in a thermometer, and the uranium in nuclear power plants were all created during such a brief and stupendous flash. The atoms produced by a star through millions of years of orderly fusion, *and* the heavy atoms generated in a few moments of unimaginable chaos, are sprayed into space (**Figure 2.4**). Every chemical element heavier than hydrogen—most of the atoms that make up the planets, the ocean, and living creatures—was manufactured by the stars.

The Formation of the Solar System

2.5

Earth and its ocean are the indirect result of a supernova explosion. The thin cloud, or **solar nebula**, from which our sun and its planets formed was probably struck by the shock wave and some of the matter of an expanding supernova remnant. Indeed the turbulence of the encounter may have caused the condensation of our solar system to begin. The solar nebula was affected in at least two important ways: First, the shock wave caused the condensing mass to spin; second, the nebula absorbed some of the heavy atoms from the passing supernova remnant. In other words, a massive star had to live its life (constructing elements in the process) and then undergo explosive disintegration in order to seed heavy elements back into the nebular nursery of dust and gas from which our solar system arose. The planets are made mostly of matter assembled in a star (or stars) that disappeared billions of years ago. We are made of that stardust. Our bones and brains are composed of ancient atoms formed by stellar fusion long before the solar system existed.

By about 5 billion years ago, the solar nebula was a rotating, disk-shaped mass of about 75% hydrogen, 23% helium, and 2% other material (including heavier elements, gases, dust, and ice). Like a spinning skater bringing in his or her arms, the

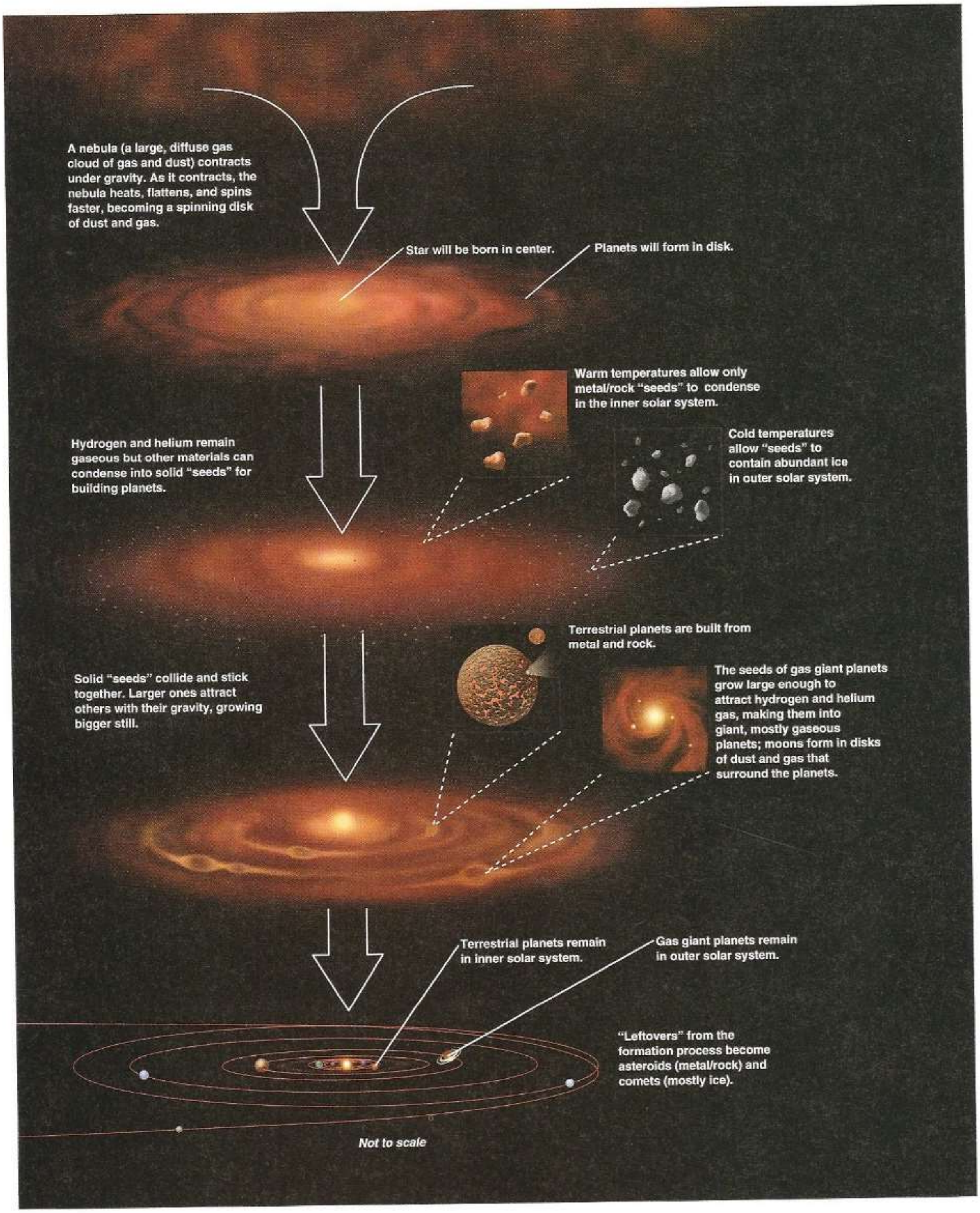
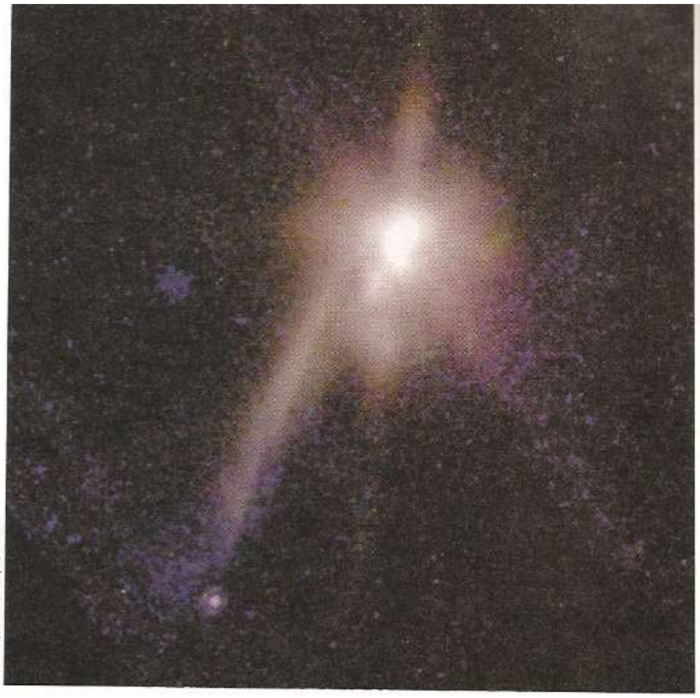


FIGURE 2.3 The origin of a solar system in the spiral arm of a galaxy. Our sun and its family of planets were formed in this way about 5 billion years ago.

European Southern Observatory

FIGURE 2.4 A photograph of the Crab Nebula, the remains of a massive star whose supernova stage was witnessed—and position marked—by Chinese astronomers in A.D. 1054. In a few tens of thousands of years it will have fully dispersed its wealth of heavy elements into the surrounding galactic gas.



Hubble Space Telescope, STScI

FIGURE 2.5 The first image of a possible planet outside our solar system. It is the small, bright object to the lower left, at the end of the filament of dust and gas extending from a newly formed sun.

nebula spun faster as it condensed. Material concentrated near its center became the protosun. Much of the outer material eventually became **planets**, the smaller bodies that orbit a star and do not shine by their own light.

Look again at Figure 2.3. The new planets formed in the disk of dust and debris surrounding the young sun through a process known as **accretion**—the clumping of small particles into large masses. Bigger clumps with stronger gravity pulled in most of the condensing matter. Near the protosun, where temperatures were highest, the first materials to solidify were substances with high boiling points, mainly metals and certain rocky minerals. The planet Mercury, closest to the sun, is mostly iron because iron is a solid at high temperatures. Somewhat farther out, in the cooler regions, magnesium, silicon, water, and oxygen condensed. Methane and ammonia accumulated in the frigid outer zones. Earth's array of water, silicon–oxygen compounds, and metals results from its middle position within that accreting cloud. The gas giant planets of the outer solar system—Jupiter, Saturn, Uranus, and Neptune—are composed mostly of methane and ammonia ices because those gases can congeal only at cold temperatures.

The period of accretion lasted perhaps 30 to 50 million years. The protosun became a star—our sun—when its internal temperature was high enough to fuse atoms of hydrogen into helium. The violence of these nuclear reactions sent a solar wind of radiation sweeping past the inner planets, clearing the area of excess particles and ending the period of rapid accretion. Gases like those we now see on the giant outer planets may once have surrounded the inner planets, but this rush of solar energy and particles stripped them away.

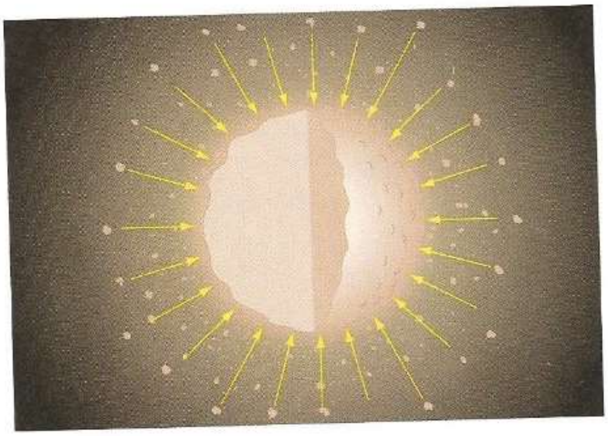
This process might not be rare. As you'll learn in Box 2.1, more than 100 planets have been discovered orbiting other stars. One of them is shown in **Figure 2.5**.

Earth and Ocean

2.6

The young Earth, formed by the accretion of cold particles, was probably homogeneous throughout. Then, during the accretion phase, Earth's surface was heated by the impact of asteroids, comets, and other falling debris. This heat, combined with gravitational compression and heat from the decay of radioactive elements accumulating within the newly assembled planet, caused Earth to partially melt. Gravity pulled most of the iron and nickel inward to form the planet's core. The sinking iron released huge amounts of gravitational energy, which, through friction, heated Earth even more. At the same time a slush of lighter minerals—silicon, magnesium, aluminum, and oxygen-bonded compounds—rose toward the surface, forming Earth's crust (**Figure 2.6**). This important process, called **density stratification**, lasted perhaps 100 million years.[3]

[3] **Density** is an expression of the relative heaviness of a substance; it is defined as the mass per unit volume, usually expressed in grams per cubic centimeter (g/cm^3). The density of pure water is 1 g/cm^3. Granite rock is about 2.7 times denser, at 2.7 g/cm^3.



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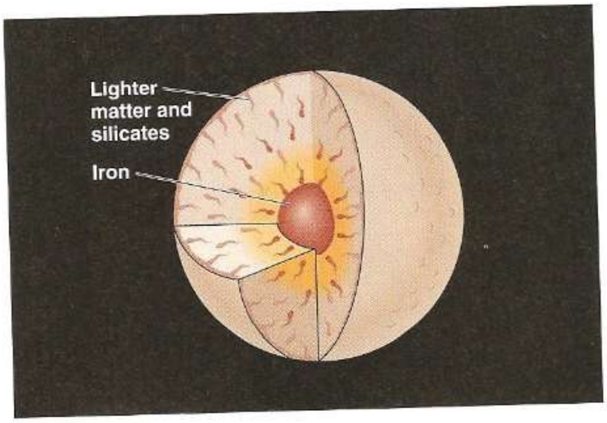

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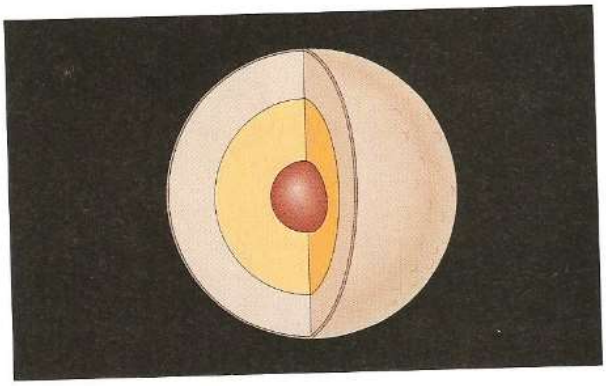


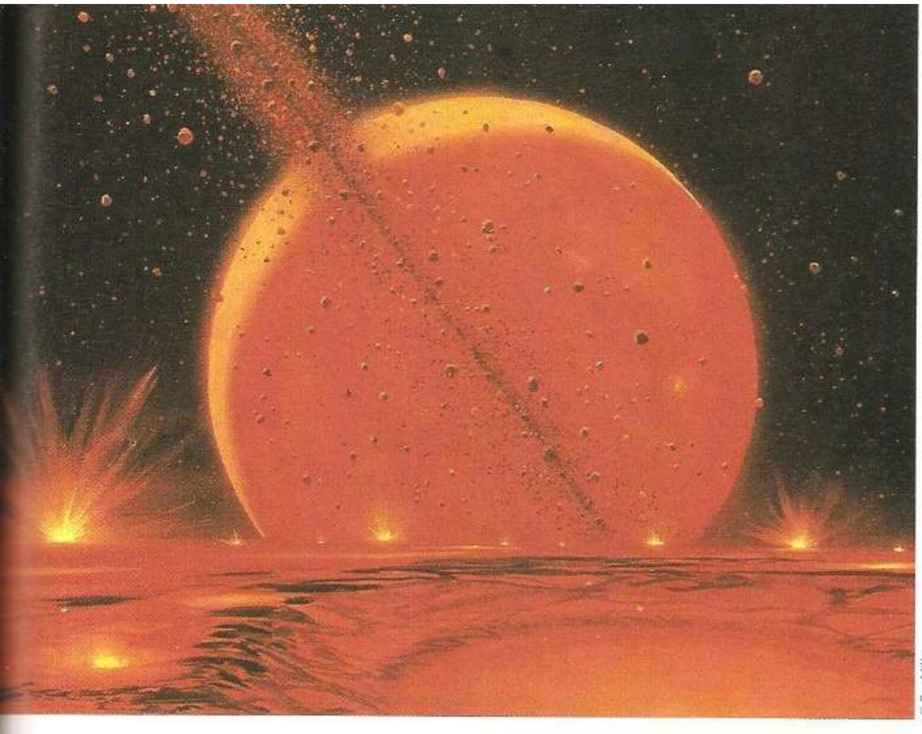
c

FIGURE 2.6 A representation of the formation of Earth. (**a**) The planet grew by the aggregation of particles. Meteors and asteroids bombarded the surface, heating the new planet and adding to its growing mass. At the time, Earth was composed of a homogeneous mixture of materials. (**b**) Earth lost volume because of gravitational compression. High temperatures in the interior turned the inner Earth into a semisolid mass; dense iron (red drops) fell toward the center to form the core, while less dense silicates moved outward. Friction generated by this movement heated Earth even more. (**c**) The result of *density stratification* is evident in the formation of the inner and outer core, the mantle, and the crust.

FIGURE 2.7 The first stage of the formation of the moon. A planetary body somewhat larger than Mars smashed into the young Earth about 4.4 billion years ago. The rocky mantle of the impactor was ejected to form a ring of debris around Earth, and its metallic core fell into Earth's core and joined with it. Rocks brought from the lunar surface by Apollo astronauts suggest the ejected material condensed soon after to become our moon.

Then Earth began to cool. Its first surface is thought to have formed about 4.6 billion years ago. That surface did not remain undisturbed for long. A planetary body somewhat larger than Mars smashed into the young Earth and broke apart (**Figure 2.7**). The metallic core fell into Earth's core and joined with it, while the rocky mantle was ejected to form a ring of debris around Earth. The debris began condensing soon after and became our moon. The newly formed moon, still glowing from heat generated by the kinetic energy of infalling objects, is depicted in **Figure 2.8**. Could a similar cataclysm happen today? The issue is addressed in Box 13.1.

Radiation from the energetic young sun had stripped away our planet's outermost layer of gases, its first atmosphere; but soon gases that had been trapped inside the forming planet burped to the surface to form a second atmosphere. This volcanic venting of volatile substances—including water vapor—is called **outgassing** (**Figure 2.9a**). As the hot vapors rose, they condensed into clouds in the cool upper atmosphere. Though most of Earth's water was present in the solar nebula during the accretion phase, recent research suggests that a barrage of icy comets colliding with Earth may also have contributed a portion of the accumulating mass of water, this ocean-to-be (**Figure 2.9b**)



© Ron Miller

FIGURE 2.8 Within a thousand years of the giant impact, our moon (foreground) was forming. In this painting the sky is dominated by a red-hot Earth, recently reshaped and melted by the moon-forming impact. The ring of debris will eventually fall to Earth or be captured by the still-growing molten moon.

© William K. Hartmann

© Dan Dixon

a

b

FIGURE 2.9 Sources of the ocean. (**a**) Outgassing. Volcanic gases emitted by fissures add water vapor, carbon dioxide, nitrogen, and other gases to the atmosphere. Volcanism was a major factor in altering Earth's original atmosphere; later the action of photosynthetic bacteria and plants was another. (**b**) Comets may have delivered some of Earth's surface water. Intense bombardment of the early Earth by large bodies—comets and asteroids—probably lasted until about 3.8 billion years ago.

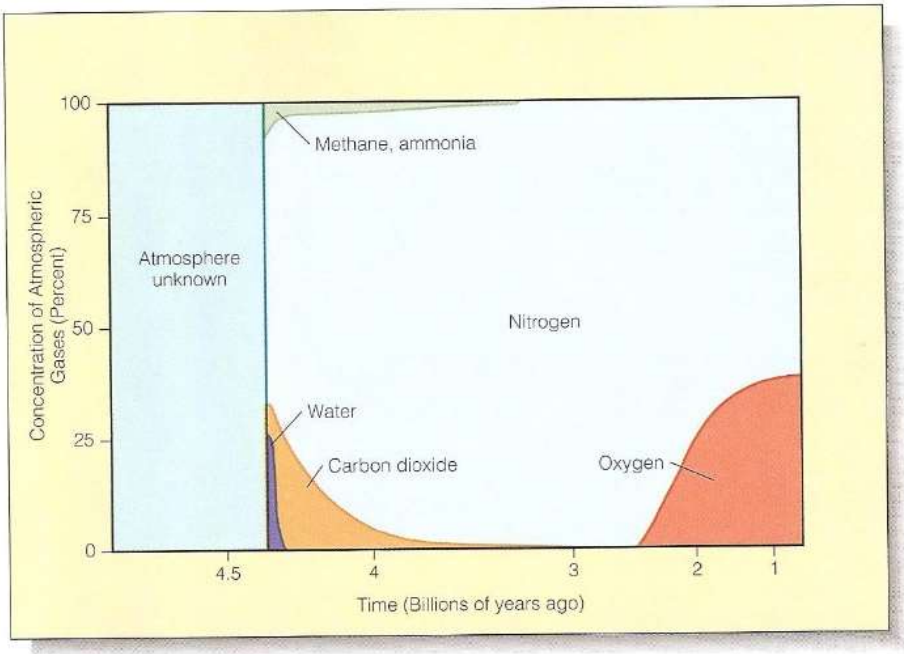


FIGURE 2.10 The evolution of our atmosphere. The early atmosphere had high concentrations of water and carbon dioxide with traces of methane and ammonia. Much of the carbon dioxide dissolved in seawater to form carbonic acid, then combined with crustal rocks. Nitrogen became the dominant gas. After the emergence of photosynthetic organisms, oxygen began to accumulate in the atmosphere. C.J. Allegre and S.H. Schneider. "The Evolution of the Earth," Scientific American, October 1994. reprinted by permission of Ian Worpole.

Earth's surface was so hot that no water could collect there and no sunlight could penetrate the thick clouds. (A visitor approaching from space 4.5 billion years ago would have seen a vapor-shrouded sphere blanketed by lightning-stroked clouds.) After millions of years the upper clouds cooled enough for some of the outgassed water to form droplets. Hot rains fell toward Earth, only to boil back into the clouds again. As the surface became cooler, water collected in basins and began to dissolve minerals from the rocks. Some of the water evaporated, cooled, and fell again. The world ocean was gradually accumulating.

These heavy rains may have lasted about 20 million years. Large amounts of water vapor and other gases continued to escape through volcanic vents during that time and for millions of years thereafter. The ocean grew deeper. Evidence suggests that Earth's crust grew thicker as well, perhaps in part from chemical reaction with oceanic compounds.

The physical expanse and distribution of the early ocean are matters of some controversy. Most researchers hold that masses of rock have always protruded through the ocean surface to form continents. However, some recent studies suggest that water may have covered Earth's entire surface for some 200 million years before the continents emerged. Although most of the ocean was in place about 4 billion years ago, ocean formation continues very slowly even today: About 0.1 cubic kilometer (0.025 cubic mile) of new water is added to the ocean each year, mostly as steam flowing from volcanic vents and in the form of microscopic cometary fragments.

The composition of the early atmosphere (often called the *primitive atmosphere*) was much different from today's (**Figure 2.10**). Geochemists believe it may have been rich in carbon dioxide, nitrogen, and water vapor, with traces of ammonia and methane. Beginning about 3.5 billion years ago, this mixture began a gradual alteration to its present composition, mostly nitrogen and oxygen. At first this change was brought about by carbon dioxide dissolving in seawater to form carbonic acid, then combining with crustal rocks. The chemical breakup of water vapor by sunlight high in the atmosphere also played a role. Then about 1.5 billion years later, the ancestors of today's green plants produced—by photosynthesis—enough oxygen to oxidize minerals dissolved in the ocean and surface sediments. Oxygen began to accumulate in the atmosphere. (This monumental event in Earth's history is called the *oxygen revolution*. You'll find more about it in Chapter 15.)

OceanographyNow™ | Click Oceanography Interactive to view an animation on the earth's layers.

The Origin of Life

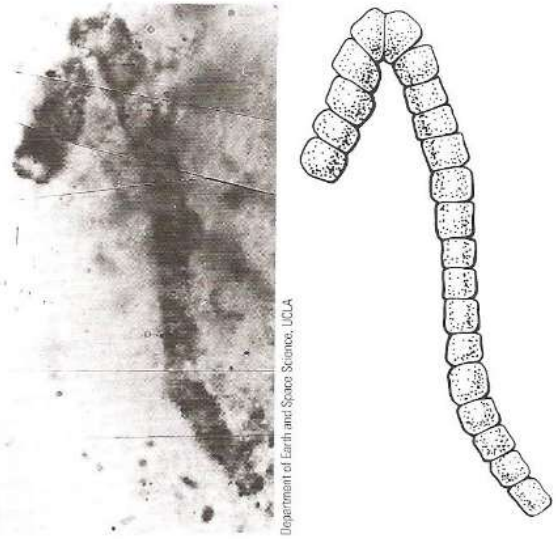
2.7

Life, at least as we know it, would be inconceivable without large quantities of water. Water has the ability to retain heat, moderate temperature, dissolve many chemicals, and suspend nutrients and wastes. These characteristics make it a mobile stage for the intricate biochemical reactions that allowed life to begin and prosper on Earth.

Life on Earth is formed from aggregations of a few basic kinds of carbon compounds. Where did the carbon compounds come from? There is growing consensus that most of the organic (that is, carbon-containing) materials in these compounds were transported to Earth by the comets, asteroids, meteors, and interplanetary dust particles that crashed into our planet during its birth.

Ralph White/Corbis

FIGURE 2.11 An environment for biosynthesis? Weak sunlight and unstable conditions on Earth's surface may have favored the origin of life on mineral surfaces near deep-ocean hydrothermal vents similar to the one shown here.



Department of Earth and Space Science, UCLA

FIGURE 2.12 Fossil of a bacteria-like organism (with an artist's reconstruction) that photosynthesized and released oxygen into the atmosphere. Among the oldest fossils ever discovered, this microscopic filament from northwestern Australia is about 3.5 billion years old.

The young ocean was a thin broth of organic and inorganic compounds in solution.

In laboratory experiments mixtures of dissolved compounds and gases thought to be similar to Earth's early atmosphere have been exposed to light, heat, and electrical sparks. These energized mixtures produce simple sugars and most of the biologically important amino acids. They even produce small proteins and nucleotides (components of the molecules that transmit genetic information between generations). The main chemical requirement seems to be the absence (or near absence) of free oxygen, a compound that can disrupt any unprotected large molecule.

Did *life* form in these experiments? No, the compounds that formed are only building blocks of life. But the experiments do tell us something about the commonality and unity of life on Earth. The facts that these crucial compounds can be synthesized so easily and are present in virtually all living forms are probably not coincidental. Those compounds are "permitted" by physical laws and by the chemical composition of this planet. The experiment also underscores the special role of water in life processes. The fact that all life, from a jellyfish to a dusty desert weed, depends on saline water within its cells to dissolve and transport chemicals is certainly significant. It strongly suggests that simple, self-replicating—living—molecules arose somewhere in the early ocean. It also suggests that all life on Earth is of common origin and ancestry.

The early steps in the evolution of living organisms from simple organic building blocks, a process known as **biosynthesis**, are still speculative. Planetary scientists suggest that the sun was faint in its youth. It put out so little heat—about 30% less than today—that the ocean may have been frozen to a depth of around 300 meters (1,000 feet). The ice would have formed a blanket that kept most of the ocean fluid and relatively warm. Periodic fiery impacts by asteroids, comets, and meteor swarms could have thawed the ice, but between batterings it would have reformed. In 2002 chemists Jeffrey Bada and Antonio Lazcano suggested that organic material may have formed and then been trapped beneath the ice—protected from the atmosphere, which contained chemical compounds capable of shattering the complex molecules. The first living molecules might have arisen deep below the layers of surface ice, on clays or pyrite crystals at cool mineral-rich seeps on the ocean floor (**Figure 2.11**).

A similar biosynthesis cannot occur today. Living things have changed the conditions in the ocean and atmosphere, and those changes are not consistent with any new origin of life. For one thing, green plants have filled the atmosphere with oxygen. For another, some of this oxygen (as ozone) now blocks most of the dangerous wavelengths of light from reaching the surface of the ocean. And finally, the many tiny organisms present today would gladly scavenge any large organic molecules as food.

How long ago might life have begun? The oldest fossils yet found, from northwestern Australia, are between 3.4 and 3.5 billion years old (**Figure 2.12**). They are remnants of fairly complex bacteria-like organisms, indicating that life must have originated even earlier, probably only a few hundred million years after a stable ocean formed. Evidence of an even more ancient beginning has been found in the form of carbon-based residues in some of the oldest rocks on Earth, from Akilia Island near Greenland. These 3.85-billion-year-old specks of carbon bear a chemical fingerprint that researchers feel could only have come from a living organism. Life and Earth have grown old together; each has greatly influenced the other.

The Distant Future of Earth?

2.8

Our descendants may enjoy another 5 billion years of Earth as we know it today. But then our sun, like any other star, will begin to die. The sun is not massive enough to become a supernova, but after a billion-year cooling period the re-energized sun's red giant phase will engulf the inner planets. Its fiery atmosphere will expand to a radius greater than the orbit of Earth. The ocean and atmosphere, all evidence of life, the crust, and perhaps the whole planet will be recycled into component atoms and hurled by shock waves into space (**Figure 2.13**). Our successors, if any, will have perished or fled to safer worlds. Its fuel exhausted and its energies spent, the sun will cool to a glowing ember and ultimately to a dark cinder. Perhaps a new system of star and planets will form from the debris of our remains.

The history of past and future Earth is shown as a time line in **Figure 2.14**.

Hubble Space Telescope, STScI

FIGURE 2.13 The end of a solar system? The glowing gas in this beautiful nebula once formed the outer layers of a sunlike star that exploded only 10,000 years ago. The inner loops are being ejected by a strong wind of particles from the remnant central star. If planets orbited this star, their shattered remnants are contained in the outward-rushing orange filaments at the periphery. Perhaps 6 billion years from now, observers 5,000 light-years away would see a similar sight as our sun passes the end of its life.

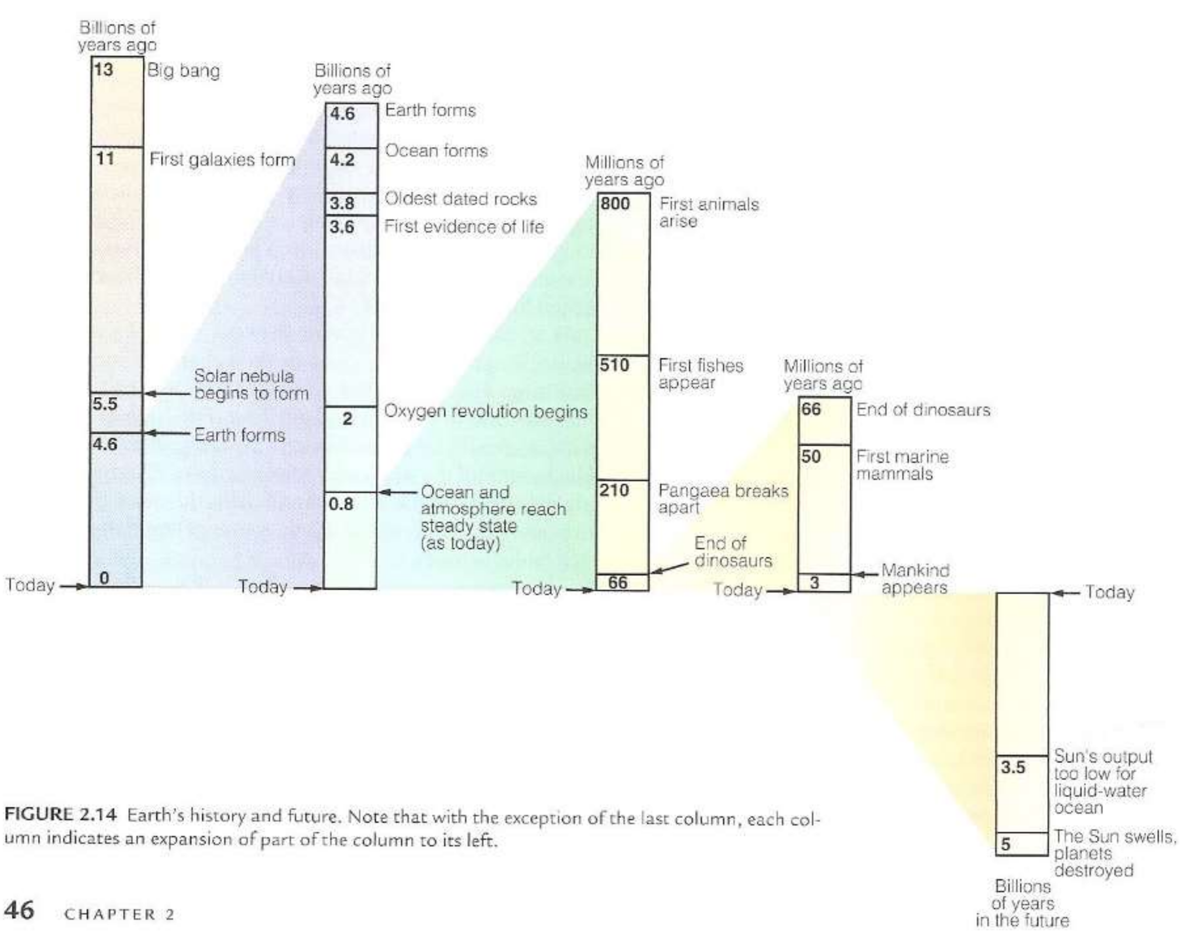


FIGURE 2.14 Earth's history and future. Note that with the exception of the last column, each column indicates an expansion of part of the column to its left.

supernova—an explosion capable of yielding such heavy elements as mercury, gold, and uranium. The second figure shows the end of a star like our sun, a relatively tame event as such things go. The intense bursts of gamma rays and X-rays from a huge supernova (a hypernova) could sterilize everything in part of a galaxy's spiral arm; nothing alive based on water and proteins would survive. The radiation from the disintegration of a sunlike star would be less catastrophic. Astronomers have detected gamma-ray bursts since the 1960s, but only in 2003 was a gamma burst directly associated with the first light from a hypernova. Fortunately the event happened in a distant galaxy.

Chapter in Perspective

In this chapter you learned that most of the atoms that make up Earth, its ocean, and its inhabitants were formed within stars billions of years ago. Stars spend their lives changing hydrogen and helium into heavier elements. As they die, some stars eject the elements into space during cataclysmic explosions. The sun and planets, including Earth, condensed from a cloud of dust and gas enriched by the recycled remnants of exploded stars.

Earth formed by accretion, the clumping of small particles into a large mass. The mass heated as it grew, eventually melting. The heavy iron and nickel crashed toward Earth's center to become its core; the lighter silicates and aluminum compounds rose to the surface to form a crust. The earth became *density stratified*—that is, layered by density.

The ocean formed as soon as Earth was cool enough for water to remain liquid. Life followed soon thereafter.

In the next chapter you will learn about Earth's inner layers—layers that are density stratified. You'll find these layers to be heavier and hotter as depth increases, and you'll learn how we know what's inside our planet even though we've never been past the outermost layer. As you'll see, today's earthquakes and volcanoes, and the slow movement of continents, are all remnants of our distant cosmological past.

Key Ideas

- ✓ The objects comprising our solar system condensed about 5 billion years ago from a thin cloud that had been enriched by heavy elements made in exploding stars.
  Review Figure 2.3 and 2.4, pages 40–41

- ✓ Earth is *density stratified*. During its formation heavy materials fell inward to form the core, and lighter substances rose to become the outer layers. Ocean and atmosphere are the least dense of these layers.
  Review Figure 2.6, page 42

- ✓ Earth first had a solid surface about 4.6 billion years ago. The ocean formed from clouds of steam and water vapor when Earth's surface became cool enough to allow liquid water to rest on the surface.
  Review Figure 2.9, page 43

- ✓ Life probably arose on Earth shortly after its formation, about 4 billion years ago. Life may have arisen in the deep ocean.
  Review pages 44–46

- ✓ Earth's atmosphere has changed substantially through time. The most dramatic change began about 2 billion years ago when photosynthetic organisms began producing large quantities of oxygen.
  Review Figure 2.10, page 44

- ✓ Other planets and moons may have—or may have had—oceans.
  Review Box 2.1, pages 47–50

Terms and Concepts to Remember

accretion, 41
big bang, 38
biosynthesis, 45
condensation theory, 39
density, 41
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galaxy, 38
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nebula, 39
outgassing, 42
planet, 41
protostar, 39
solar nebula, 39
solar system, 38
star, 38
supernova, 38–39

Study Questions

Reviewing What You've Learned

1. How old is Earth? On what are those estimates based?
2. What is the relationship between galaxies and stars? What things make up galaxies?
3. What element makes up most of the detectable mass in the universe?
4. Briefly trace the life of a typical star.
5. How are planets and stars related?
6. How are light elements converted into heavy ones?
7. Will all stars end their lives as supernovas? What happens to the heavy elements made by small stars?
8. What is density stratification? What does it have to do with the present structure of Earth?
9. Are the ocean and present atmosphere "leftovers" from the original atmosphere of Earth?
10. What is biosynthesis? Where do researchers think it might have occurred on our planet? Could it happen again today?

Vragen bij les 1

1. Mariene biologen zeggen soms dat alle levensvormen op aarde, inclusief landdieren, marien zijn. Waarom?

2. Waar kwam het oppervlakte water op de aarde vandaan?

3. Denk je dat waterplaneten veel voorkomen in het heelal? Waarom?

4. Op welke manier zou de aarde anders zijn als er geen oceaan was gevormd?

5. Welke atmosferische verandering maakte dierlijk leven mogelijk?

6. Kunnen er nu afstammelingen van de meeste vroege soorten in de oceanen gevonden worden? Leg uit waarom.

7. Denk je dat er meer diersoorten zijn op het land of in de oceaan? En waar is het totale aantal dieren groter?